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SOME SOIL PROPERTIES OF THE GRABAG-PRINGSURAT PALEOCHANNEL (CENTRAL JAVA) INDICATING THE FATE OF PEDOGENESIS UNDER A SPECIFIC GEOMORPHOLOGICAL SITUATION

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ABSTRACT

Along with landform development, the soil on a landform also undergoes development characterized by various changes in physical and chemical characteristics. In this paper, we present the results of an investigating in to the physical and chemical characteristics of the soil in the paleochannel. The study was conducted in the Grabag-Pringsurat area where there are paleochannels with Pleistocene-aged materials. The study implemented the synthetic soil survey method. Nine paleochannels were selected as samples for observation. The data was then analyzed descriptively. There are two significant findings in this study. First, the physical properties of the soil are characterized by a dark color, fine-loamy texture, structural arrangement with strong aggregates, and strong consistency. In contrast, the chemical properties are characterized by acidic soil reactions. Second, soil properties are more developed in paleochannels filled with older materials. Overall, this study provides alternative information that reinforces the concept of soil development as an integral part of landform development.

A. INTRODUCTION

Soil is the material covering the Earth's surface, closely related to landforms. Soil development is an integral part of landform development. In other words, soil development occurs along with landforms, and there is a mutually influencing relationship between soil development and landforms. Huggett (2023) explains that soil and landforms are interrelated in soil-landscape systems. Soils and landforms are spatially interconnected and develop together as interacting systems. Minasny et al. (2015) also explain that the development of soils and landforms is co-evolutionary, influencing each other on geological and ecological time scales.

Since soil development is closely related to landform development, it is essential to look at it on landforms that

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are also undergoing evolution and development. One landform that exhibits such characteristics is the paleochannel. This morphology is a river valley abandoned by the stream due to a process that causes the damming or disconnection of the upstream flow source.

Paleochannel occurs in river valleys and is not only a product of fluvial processes. In other landscapes where there is river flow, it is also possible to form paleochannels, including in volcanic environments, as found in studies in the Merapi Volcano and Borobudur Basin, Indonesia (Ashari, 2022; Ashari et al., 2021; Gomez et al., 2010; Maruyama, 1993; Murwanto et al., 2004); Mayon Volcano, Philippines (Paguican et al., 2009); and Santiaguito Volcano, Guatemala (Harris et al., 2006). Thick volcanic product material in the paleochannel, which is no longer affected by river flow, can then develop into soil over time under the influence of local climate, organisms, and relief.

The study of soil development in paleochannels is an interesting topic that proves the relationship between soil development and landform development. However, such studies are still relatively lacking. Discussions on paleochannels are generally limited to morphology, morphogenesis, or morphochronology within the field of geomorphology. The influence of paleochannels on the environment is mainly associated with groundwater potential as an implication of the basin morphology, as has been presented by previous authors such as Mulligan et al. (2007). Meanwhile, there is a lack of discussion on soils despite the potential for studies on soil-landform relationships in paleochannels. This shows a knowledge gap, and studies on this topic are critical.

In the Grabag-Pringsurat region of Central Java, many paleochannels developed in volcanic environments. Interestingly, these paleochannels are not located or influenced by young Holocene-aged volcanic activity, as in the neighboring areas of Merapi and Borobudur, but the underlying volcanic activity is older. Examination of the geologic map shows that the materials on the valley floor are mostly Pleistocene in age.This relatively old material allows a long pedogenesis process to develop into soil. The extent of the soil development stage is characterized by the physical and chemical properties of the soil at the base of the paleochannel. Given the presence of these old materials, the paleochannel in the Grabag-Pringsurat region is a good place to investigate soil properties as a proxy, indicating the relationship between soil development and landform evolution.

In this paper, we present the results of an investigation into some of the physical and chemical characteristics of paleochannel soils in the Grabag-Pringsurat region of Central Java. This study has two more specific objectives. First, to analyze some of the paleochannel soils' physical and chemical properties. Second, to analyze the spatial variability of soil physical and chemical properties concerning landform age and development. Concerning these two objectives, this study provides alternative information reinforcing the relationship between development and landform development. It also contributes new information that fills the gap about the lack of studies on paleochannel soils.

This study offers new insights into soil properties in paleochannels, in the context of soil-geomorphology relationships. The relationship between soil and geomorphology is close, with soil development viewed as an integral part of geomorphological development (Sartohadi et al., 2016). Regarding this, many geomorphological studies of soil have also been conducted in Indonesia.

Previous studies generally examined various types of soil that developed across different landforms and materials (Aji et al., 2024; Riyanto et al., 2022, or the influence of soil geomorphology on vegetation (Tirta Pratiwi et al., 2020). No studies specifically examining the characteristics of Pleistocene paleochannels have been found. In Indonesia, numerous studies on paleochannels have been conducted.

However, these studies have focused on identifying the morphology of paleochannels (Kurnio & Aryanto, 2016; Muhammad et al., 2024; Noviadi, 2017; Yanis et al., 2019) or the development (Ashari, 2022; Ashari et al., 2021), rather than the characteristics of the soil within them. These various facts indicate that studies on soil characteristics in paleochannels have not yet been conducted in Indonesia. Thus, this study provides a new direction for soil geomorphology research and offers new insights into the characteristics of soil that develops in paleochannels.

B. METHOD

B.1. DATA COLLECTION AND ANALYSIS

This study was conducted using a geographic approach, namely a spatial approach, where the distribution of paleochannels in the study area is a varied phenomenon and needs to be approached spatially. This study also applies geography themes to answer the problems: location, place, human-environment interaction, region, and movement.

This study also implements synthetic geomorphological and soil survey methods. The subject of this study is the paleochannel in the Grabag-Pringsurat area. In contrast, the study's object is the soil's physical and chemical characteristics in the paleochannel.

Figure 1. Measurement Data in the Field. (A) Measurement with soil auger (July 2, 2023), (B) Measurement on soil outcrops (June 23, 2023), (C) Disturbed soil sampling (May 3, 2025), (D) Soil samples for laboratory tests

(Source: Fieldwork, 2023-2025)

This study implemented a synthetic soil survey method. This survey method is characterized by a relatively limited number of observation samples and purposive determination of observation locations, which is based on the theory of soil unit distribution. Climate, organisms, parent material, relief, and time influence the distribution of soil units. Since this study is focused on investigating soil properties in the paleochannel, the sampling in the paleochannel refers to the theory of soil unit distribution. Field observations in this study were made with soil auger (Fig. 1A), as well as excavation of soil profiles and utilization of soil outcrops (Fig. 1B). Some soil samples were taken from the field as disturbed soil samples for laboratory testing (Fig. 1C). This sampling of disturbed soil is possible because the analysis conducted in the laboratory is a soil texture analysis (Fig. 1D).

Table 1. Data in the study and methods of collection

Data	Data collection method	Instrument/data sources
Soil color	Observation	Munsell soil color chart, soil auger, observation sheet
Soil texture	Observation	Soil test kit, sample bag, label paper, soil auger, observation sheet
	Laboratory testing	Soil sieve, oven, scales
Soil structure	Observation	Soil test kit, shovel, geological hammer, observation sheet
Soil consistency	Observation	Soil test kit, sample bag, label paper, soil auger, observation sheet
Soil reaction	Observation	Soil pH-moisture meter, soil test kit, observation sheet
Soil moisture	Observation	Soil pH-moisture meter, observation sheet
Material	Document analysis	Geological Map of Magelang-Semarang 1408-5 and 1409-2
Landform	Document analysis	Indonesian Topographical Map sheet 1408-521 Tegalrejo and 1408-523 Grabag
	Observation	GPS, geological compass, Jalon stick, Abney level, roll meter, observation sheet
Sample location	Observation	GPS, digital camera, observation sheet
Landuse	Document analysis	Indonesian Topographical Map sheet 1408-521 Tegalrejo and 1408-523 Grabag
	Observation	Digital camera, observation sheet

(Source: research design, 2023)

This study used primary data obtained from field observations. Primary data included all soil physical and chemical properties variables, including soil color, soil texture, soil structure, soil consistency, soil reaction, and surface soil moisture. This primary data is supported by secondary data in the form of lithology, morphology, and land use obtained from Geological Maps and Indonesian Earth Maps. The relationship between data types, data collection methods, instruments used, and data sources is shown in Table 1. Meanwhile, the methods of measuring soil physical and chemical properties are shown in Table 2.

Table 2. Procedure for measuring the physical and chemical properties of soil

Variable	Method of measurement
Soil color	Color measurements were taken in the field using the Munsell Soil Color Chart. Soil samples in moist conditions were taken and matched with the corresponding color in the book, and then the color name, hue, value, and chroma were recorded.
Soil texture	Soil texture measurements in this study were conducted qualitatively and quantitatively. • Qualitative measurements were made in the field during the soil sampling process. In this method, a small amount of soil sample is taken and wetted, and the roughness is felt with the fingers. In addition, a ribbon-like shape is also made, whether it is shaped, cracked, or cannot be shaped at all. • Quantitative measurements are taken in the laboratory. Soil samples are oven-dried first; then, the aggregates are released and separated into fractions using a Griffith Co. soil sieve. The separated soil fractions are weighed to determine their weight and percentage, and then the texture type is specified on the soil texture triangle.
Soil structure	Soil structures are observed in profiles or soil sections found in the field. The type of structure can be seen based on the shape that appears in the cross-section that has been made. In addition, its quantitative dimensions can be measured using a ruler.
Soil consistency	Soil consistency measurements in this study were conducted qualitatively in the field. Soil consistency was measured under wet, moist, and dry conditions. • In wet conditions, adhesion and plasticity were measured. Adhesiveness is tested by pressing the soil sample on the finger and releasing it. How firmly the soil sample sticks to the finger indicates the degree of adhesion. Stickiness is also tested by wetting the soil sample, rolling it up, and pressing it. In this process, whether or not the soil sample has cracks or is easily deformed is noted. • Under moist and dry conditions, consistency is tested by crushing the soil aggregates, either by finger massage for small samples or by palm gripping for lumpy aggregates. The amount of effort required to crush the soil aggregates indicates the consistency of the soil.
Soil reaction	Electric and colorimetric methods were used to make soil reaction measurements. • In the electric method, a soil pH-moisture meter is used. This instrument is immersed in the soil to the limit of the silvery and golden-colored metal, the electrode. After immersing, wait until the needle on the screen reads the pH value. • The colorimetric method uses a universal pH paper indicator instrument and test tubes. Soil samples are taken and then dissolved using Aquadest. In the test tube, the soil is inserted up to about one-third, and then the Aquadest is about two-thirds. These two materials are mixed and left until the soil particles settle. Next, a universal pH paper indicator was dipped in the soil solution, and the pH number was determined based on the corresponding color on the box.
Soil moisture	Soil moisture is determined using a soil pH-moisture meter. The working steps are the same as measuring soil reaction by electric means; the instrument is immersed to the entire metal limit, then press the white button and read the number indicated by the needle on the screen.
Soil depth	Soil depth or solum is determined by excavating with a soil drill, starting from the topmost soil layer to the regolith. This is the primary method used, along with profile excavation or utilization of soil outcrops in sloping or eroded areas.

(Source: research design, 2023)

The data that has been obtained is then analyzed descriptively. The analysis begins by matching the measurement data with specific criteria for soil physical and chemical properties, especially concerning the level of soil development. Descriptive analysis was supported by statistical analysis using independent-samples t-tests and by descriptive statistics to present field data in the form of tables, graphs, and boxplots. We also conducted a descriptive soil horizon analysis to examine soil properties in relation to the positions of the epipedon and endopedon.

B.2. THE STUDY AREA

This research was conducted in the Grabag-Pringsurat area, Central Java Province. This area borders two districts in Central Java Province: Magelang District and Temanggung District. The Grabag sub-district includes the Magelang district, while the Pringsurat sub-district is included in the Temanggung district. Astronomically, the study area is located at coordinates between 417704.3 and 428981.5 Meters East and between 9189532.6 and 9181873.7 Meters North in the UTM system zone 49 S. The study area is 91 km^2 (Figure. 2).

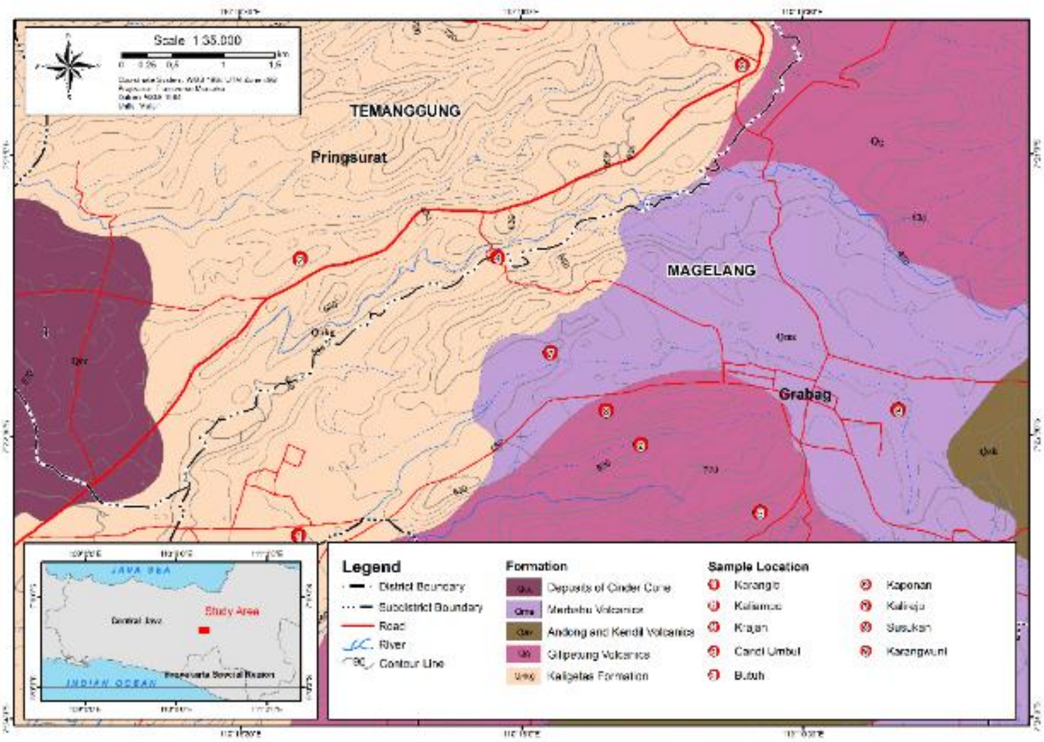

Figure 2. The Study Area

(Source: Data analysis, 2025)

In the Holocene, Merbabu Volcano was formed, which also impacted the formation of materials in this region. Merbabu Volcano began to develop in the late Pleistocene. This volcano experienced two eruptions recorded in history, namely in 1560 and 1797, both were categorized as explosive eruptions with an estimated VEI-2. In addition, at least 22 pyroclastic layers from magmatic and phreatomagmatic eruptions and one eruption estimated to reach the VEI-4 scale have also occurred at Merbabu in the period >1,900 years ago.

The VEI-4 eruption produced large amounts of material that covered an area of ~354 km², including the west and north of Merbabu (Suhendro et al., 2025)(Suhendro et al., 2025)(Suhendro et al., 2025)(Suhendro et al., 2025)(Suhendro et al., 2025). These materials have impacted the physiographic development of the Grabag-Pringsurat region, particularly in the area around the foot of the Gilipetung, Andong, and Telomoyo volcanoes. These older materials are the parent material for the soils that developed at the base of the paleochannel.

C. RESULT AND DISCUSSION

C.1. RESULT

In the Grabag-Pringsurat region of Central Java, there are many paleochannels. No less than 19 paleochannels are spread over an area of 91 km^2. The paleochannels vary in size, shape, and orientation. Among the 19 paleochannels in this study, more detailed observations were made on nine paleochannels that were used as sampling soil measurements, namely Karanglo, Kaliampo, Krajan, Candi Umbul, Butuh, Kaponan, Kalirejo, Susukan, and Karangwuni (Table 3 and Fig. 3). The length of the paleochannels used as sample locations ranged from 1.3 to 8.1 km. The shortest paleochannel is Karanglo and the longest is Candi Umbul. The width of the paleochannel ranges from 127 to 494 meters. Karangwuni paleochannel is the narrowest, while Kalirejo is the widest.

The paleochannel area can be determined by considering the length and width dimensions. The narrowest paleochannel is Karangwuni, which is 0.32 km^2, while the widest is Candi Umbul, which reaches 2.81 km^2. The maximum depth of the paleochannel valley with the surrounding land varies between 19 meters in Kaliampo Paleochannel, the minimum value, and 93.5 meters in Candi Umbul Paleochannel, the maximum value.

This paleochannel morphometry provides crucial information, namely that the Grabag-Pringsurat paleochannel has different characteristics from paleochannels in other volcanic landscapes, for example, in the volcanic foot of Merapi Volcano or in the Borobudur Basin, which is surrounded by a stratovolcano. The Grabag-Pringsurat paleochannel does not appear to be simply a river that has shifted its course due to blocked flow, but indeed, an ancient river valley that once flowed across and through the hills then lost its flow and became a paleochannel. More importantly, this paleochannel is old, having developed since the Early Pleistocene. This is indicated by the type of material that is dominated by the products of Pleistocene-aged volcanic activity. The old material allows the pedogenesis process to be advanced, so this paleochannel represents soil development as an integral part of landform development.

Table 3. Paleochannel Sample Location for Soil Properties Measurement

No	Sample Location	Coordinate (UTM)		Administrative
		X	Y	
1	Karanglo	420560	9183764	Kalikuto village, Grabag Sub-District, Magelang
2	Kaliampo	420576	9186478	Kebumen village, Pringsurat Sub-District, Temanggung
3	Krajan	424910	9188379	Rejosari village, Pringsurat Sub-District, Temanggung
4	Candi Umbul	422511	9186496	Kartoharjo village, Grabag Sub-District, Magelang
5	Butuh	425087	9183989	Sumurarum village, Grabag Sub-District, Magelang
6	Kaponan	426441	9184994	Grabag village, Grabag Sub-District, Magelang
7	Kalirejo	423031	9185556	Banyusari village, Grabag Sub-District, Magelang
8	Susukan	423577	9184990	Banyusari village, Grabag Sub-District, Magelang
9	Karangwuni	423915	9184654	Banyusari village, Grabag Sub-District, Magelang

(Source: field data, 2023)

The soil at the base of the paleochannel generally has a thick solum (Fig 4). The paleochannel's soil thickness exceeds 50 cm, except for the Karangwuni Paleochannel, which is only 25 cm thick. The thickness of the soil in the study area ranges from the thickest, the Butuh paleochannel (220 cm), Candi Umbul (110 cm), Krajan (100 cm), Karanglo (100 cm), Susukan (80 cm), Kaliampo (70 cm), Kalirejo (50 cm), Kaponan (50 cm), and Karangwuni (20 cm). The thick soil solum indicates that the pedogenesis process has been going on for a long time, with the process of addition, subtraction, translocation, and transformation. This paleochannel also did not receive a drastic addition of soil parent material; therefore, this thick soil solum is a product of weathering the parent material in situ, which has been going on for a long time.

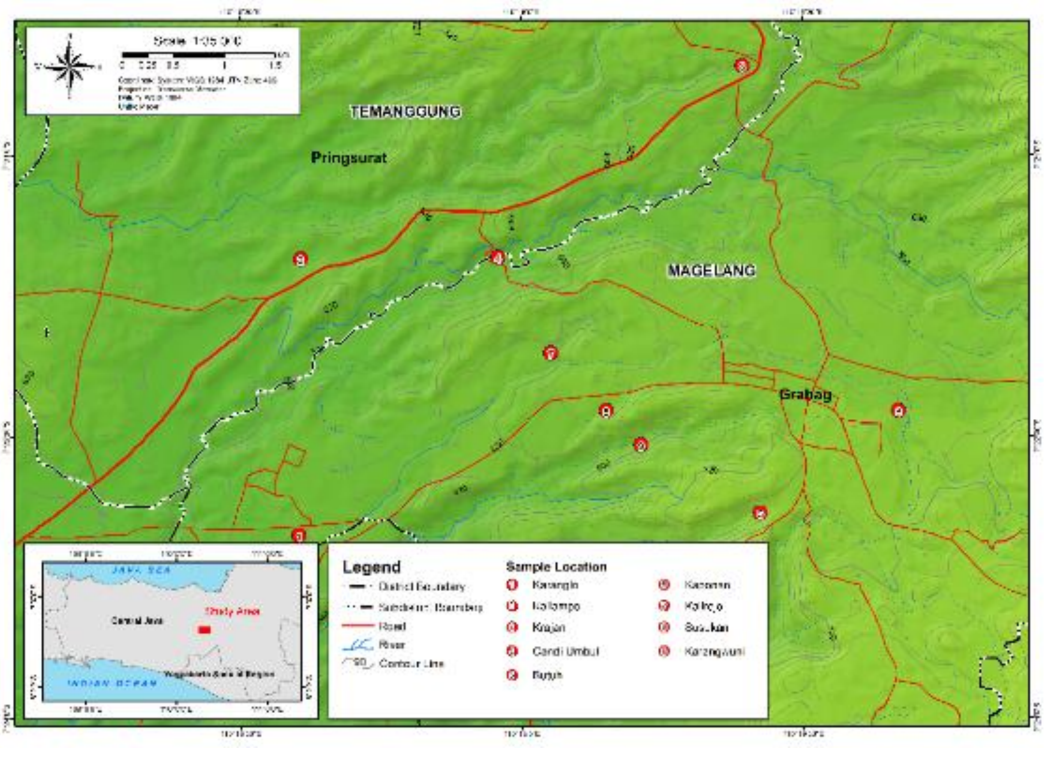

Figure 3. Distribution of Paleochannel Sample Points in the Study Area

(Source: Data analysis, 2025)

Among the nine paleochannels in this study, five were covered by Pleistocene (pre-Merbabu) material, and four were covered by Holocene material from Merbabu Volcano. Based on the material, five paleochannels were considered to belong to the older generation, while the other four were younger.

The results of the independent-samples t-test show a significant difference in average soil solum between older and younger paleochannels. Older paleochannels have a thicker average soil solum due to long-term weathering. Meanwhile, younger paleochannels have a thinner soil solum, with Merbabu pyroclastic material as the underlying parent material.

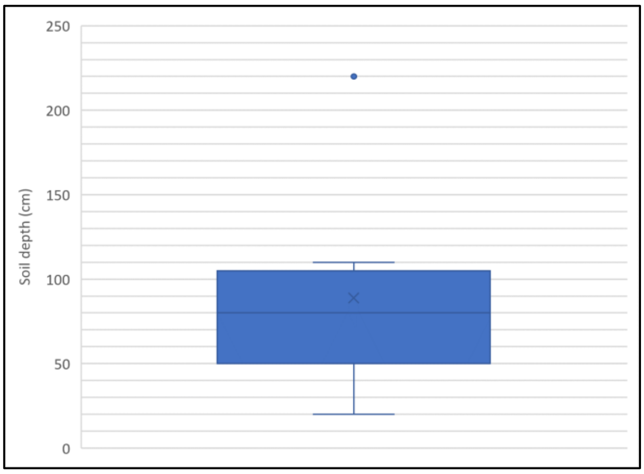

Figure 4. Boxplot for Soil Depth in the Paleochannels

Soils in the Grabag-Pringsurat paleochannel have diverse physical and chemical characteristics. This study analyzed surface soil moisture, soil color, soil structure, soil consistency, soil texture, and soil reaction. At the end of the rainy season in May 2025, surface soil moisture in the paleochannel was generally very high. Only Karanglo (25%) and Karangwuni (28%) were dry among the nine paleochannels used as samples in this study.

Other paleochannels still have high surface soil moisture, such as Kaponan (75%), Butuh (80%), and five more paleochannels with surface soil moisture above 90%. This high moisture cannot be separated from the ongoing rainfall and the use of irrigated rice fields in most paleochannels.

Regarding soil color, paleochannel soils tend to have the same color throughout the solum cross-section from the surface to the lower horizon. Some of them show darker soil color in the lower horizon. The soil in Karanglo paleochannel is brown (7.5YR 4/2) to dark brown (7.5YR 3/2).

The brown color is 0-20 cm deep, while the soil is dark brown at 100 cm. In the Kaliampo Paleochannel, the soil color throughout the solum is dark brown (7.5 YR 3/2), starting from the surface to a depth of 70 cm. The Krajan Paleochannel is dark brown (7.5YR 3/2) at a depth of 9 to 50 cm and very dark brown (7.5YR

2.5/2). In Candi Umbul paleochannel, the soil color ranges from dark brown (7.5 YR 3/2) from the surface to 70 cm depth to very dark grey (7.5 YR 3/1) at 70-100 cm depth.

In Butuh Paleochannel, the soil is dark brown with brown inserts. The dark brown color is found at depths of 0-10 cm and 20-30 cm (7.5 YR 3/3), 30-60 cm (7.5 YR 3/2), 60-150 cm (7.5 YR 3/4), and 150-220 cm (7.5 YR 3/2). Meanwhile, brown inserts are found at a depth of 10-20 cm (7.5 YR 4/4). In the Kaponan Paleochannel, the soil is dark brown throughout, 0-40 cm (7.5 YR 3/2) and 40-50 cm (7.5 YR 2.5/2). In the Kalirejo Paleochannel, the soil is dark brown (7.5 YR 2.5/2) from the surface to a depth of 40 cm, but there is a black color (7.5 YR 2.5/1) at 40-50 cm depth.

The Susukan Paleochannel also has a dark brown soil color throughout from 0-80 cm depth with variations of 7.5YR 3/3 at 0-20 cm and 40-80 cm depth, 7.5YR 2.5/2 at 20-30 cm depth, and 7.5YR 3/4 at 30-40 cm depth. Finally, in the Karangwuni Paleochannel, where the soil solum is thin, the soil is dark brown 7.5 YR 3/4. A summary of soil color comparisons between various paleochannels is shown in Table 4.

The soil structure of the paleochannel in the study area varies from blocky to massive. The blocky structure is related to the climate in the study area, which is characterized by an apparent alternation of dry and rainy seasons. The blocky structure is the type of soil structure in the upper horizon, including 0-20 cm depth in Susukan paleochannel, 0-50 cm depth in Kaliampo paleochannel, 0-20 cm depth in Krajan paleochannel, 0-80 cm depth in Karanglo paleochannel, 0-40 cm depth in Kaponan paleochannel, 0-10 cm depth in Candi Umbul paleochannel.

In the lower horizon, there are massive structures in various paleochannels. Meanwhile, in Karangwuni, Butuh, and Kalirejo paleochannels, only blocky structures exist in all parts of the soil. This blocky structure is relatively thick, with an average diameter of up to 5 cm. This is due to the high clay content that encourages the formation of large aggregates instead of small clods.

The soil in the paleochannel in the Grabag-Pringsurat area has developed. One indicator is the level of consistency influenced by high clay content. In wet conditions, the soil varies between slightly sticky, sticky, and very sticky, and somewhat clayey, clayey to very clayey. In Karangwuni Paleochannel, all parts of the soil are sticky and slightly clayey. The consistency in the Candi Umbul Paleochannel is sticky and clayey at a depth of 0-70 cm, while 70-110 cm is rather sticky and slightly clayey.

Table 4. Summary of soil color variability in paleochannels

No	Sample Location	Soil Color		Pedogenesis Indication
		Epipedon	Endopedon	
1	Karanglo	Brown	Dark Brown	There is an accumulation of clay in the lower horizon, causing a darker color.
2	Kaliampo	Dark Brown	Dark Brown	The pedogenesis process has progressed to an advanced stage, resulting in dark-colored, homogeneous soil in all horizons.
3	Krajan	Dark Brown	Very Dark Brown	Similar with 1
4	Candi Umbul	Dark Brown	Very Dark Brown	Similar with 1
5	Butuh	Dark Brown and Brown	Brown	There is a horizon that undergoes eluviation, resulting in a lighter color.
6	Kaponan	Dark Brown	Dark Brown	Similar with 2
7	Kalirejo	Dark Brown	Dark Brown	Similar with 2
8	Susukan	Dark Brown	Dark Brown	Similar with 2
9	Karangwuni	Dark Brown	Dark Brown	Similar with 2

The soil consistency in the Kaponan Paleochannel is sticky and clayey throughout. A somewhat sticky and slightly clayey consistency is found throughout the Karanglo Paleochannel. In the Krajan Paleochannel, the soil is sticky and clayey throughout. In Kaliampo, Kalirejo, and Butuh Paleochannel, all parts are somewhat sticky and slightly clayey. Meanwhile, in the Susukan Paleochannel, the surface at a depth of 0-20 cm is sticky and clayey, while at a depth of 20-80 cm, it is rather sticky and slightly clayey.

Under moist conditions, soil consistency varies greatly. In the Susukan Paleochannel, the soil consistency is very loose when moist and soft when dry. In the Kalirejo Paleochannel, the consistency is highly variable. The soil at the surface, at a depth of 0-20 cm, is loose when moist and soft when dry, while the soil below is firm when moist and hard when dry. The same condition is found in the Butuh Paleochannel, where the soil at the surface (0-20 cm) is loose, turning very firm with depth (20-150 cm) and extremely firm in the lower layers (150-220 cm).

Figure 5. Boxplot for pH value in the paleochannels

In dry conditions, the soil consistency is hard throughout. In the Kaliampo paleochannel, the whole section is also hard when dry. The upper horizon (0-40 cm) is firm in moist conditions, while the lower horizon (40-70 cm) is very firm. In Karangwuni Paleochannel, the soil consistency in moist conditions is very firm, while in dry conditions, it is hard. Different conditions are found in the Krajan and Candi Umbul Paleochannels, where the soil samples are loose when damp and soft in dry conditions. In Karanglo and Kaponan Paleochannel, all parts of the soil are also soft when dry but firm in moist conditions.

The clay fraction strongly dominates the soil texture in most of the paleochannels. This condition indicates that the pedogenesis process and soil development have taken place at an advanced level. The clay fraction in the Kalirejo, Krajan, Karanglo, Susukan, Kaliampo, and Candi Umbul paleochannels ranges from 50-60%. In the Butuh paleochannel, the dust fraction dominates with a 40-50% range.

Meanwhile, in Kaponan and Karangwuni Paleochannel, there is a relatively large sand content. Generally, the dominant soil texture in the study area is loam, dusty loam, or sandy loam. This texture is relatively the same throughout the thickness of the soil solum due to the advanced pedogenesis process. Therefore, it is challenging to identify surface and subsurface horizons based on textural characteristics, soil structure, and soil color.

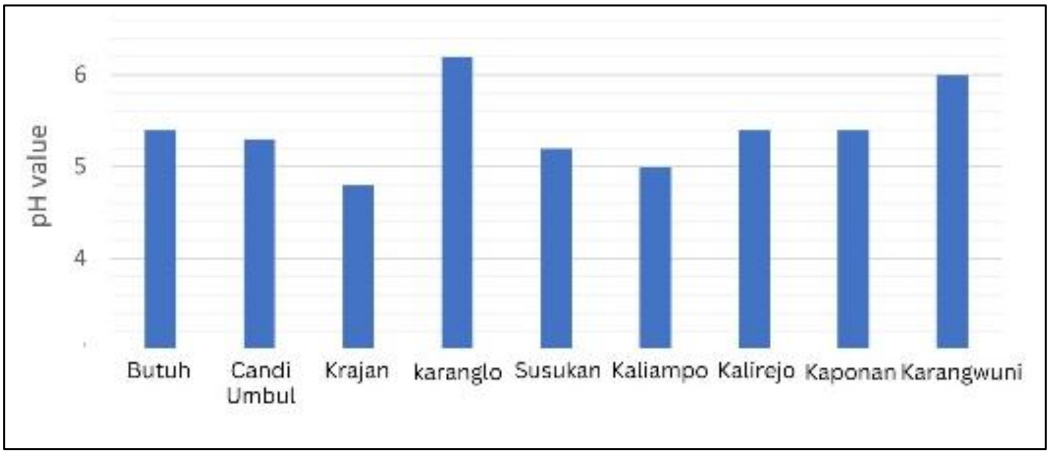

Figure 6. Variability of the soil reaction in all paleochannels

Unlike the relatively variable physical properties of soil, testing soil reaction as a soil chemical property in this study did not show significant variation. Field measurements show that soil reaction ranges from slightly acidic to acidic. Relatively striking results were found in the Krajan Paleochannel with a pH value of 4.8. The flooded paleochannel with slow infiltration causes this condition. The pH value range is shown in Fig. 5, while the variation between paleochannels is shown in Fig. 6.

C.2. DISCUSSIONS

Soil development is an integral part of landscape development. This study found soil with advanced development characteristics in paleochannels in the Grabag-Pringsurat area, Central Java, dating back to the Pleistocene. This soil is characterized by a thick solum, massive and lumpy structure with large size; clayey, sticky, firm, and hard consistency; and sandy texture.

Additionally, the soil exhibits extremely high moisture content on the surface at the end of the rainy season. The extensive use of rice fields in the study area is one of the factors contributing to this high soil moisture content. Agricultural activities using chemical fertilizers also cause the soil to become more acidic, in addition to the inherent acidic nature of the volcanic parent material. This finding validates that soil also undergoes further development in older landforms.

The findings of this study can be compared with previous results. In Spain, Jimenez-Ballesta et al. (2024) surveyed old mountains and showed that the role of parent material is significant in soil's development characteristics. Similar to our findings in the Grabag-Pringsurat paleochannel, the flat topography and sufficient time for soil formation allowed for intensive pedogenesis.

The main soil formation processes were intensive weathering and clay enrichment in the horizon with illuviation. The soil reaction in these old mountains is also acidic/slightly acidic with low base saturation. With these similarities, the study in the Grabag-Pringsurat paleochannel reinforces the soil properties of old landscapes that are rich in clay, thick, and tend to be acidic.

In Iran, Owliaie et al. (2018) also succeeded in finding a relationship between soil and landscape. This study analyzed soil in nine pedons in different physiographic positions, namely highlands, river alluvial plains, piedmont plains, and fan-shaped alluvial plains. The results showed that the most developed soil was found in stable highlands and foothills. The illuviation of clay and the development of argillic horizons in soils on more stable alluvial plains are indicators of this development.

Compared to these findings, the study's results in the Grabag-Pringsurat paleochannel also show that soils will develop further on stable landforms. The difference is that in southwestern Iran, the stable areas for pedogenesis are in the mountains and foothills, while the active fluvial areas are unstable. In Grabag-Pringsurat, the paleochannel is considered a stable terrain because it is no longer influenced by fluvial processes post-Pleistocene. Here, we validate the importance of landform stability on actual geomorphic processes in pedogenesis. Although our study was conducted in a valley, the valley here is geomorphologically stable rather than still affected by fluvial processes.

A study on the relationship between fluvial landforms and soil development was conducted in the Mahananda Sub-Basin, India (Reza, 2022). This study examined soil in 200 soil profiles in old alluvial plains, young alluvial plains, meander plains, and floodplains. The results of this study indicate that pedogenesis processes are more intensive in older landforms.

Additionally, there are similarities between the findings of this study and our results in Grabag-Pringsurat, namely that soils in meander plains have low value and chroma due to poor drainage conditions and high groundwater levels, indicating gleying characteristics. Our results also show consistently low values and chroma in all samples and depths.

The study of the Mahananda Sub-Basin explains the low value and chroma, which are due to the morphological characteristics of the valley itself, which collects runoff, leading to flooding and reduction. The high soil moisture percentage we found in Grabag-Pringsurat further supports our justification for these findings.

In general, studies on soil properties in paleochannels are still relatively rare. Few previous publications have discussed soil properties, development, or paleochannels' pedogenesis. Earlier studies used as comparisons for this study were also conducted on old non-paleochannel landforms or river-related landforms that were not yet old. Given this situation, our study in Grabag-Pringsurat provides alternative information on soil properties that indicate soil development in old landforms, particularly in paleochannels.

The results of this study enrich our understanding of long-term soil development that occurs alongside landform development. This study contributes to new insights into pedogenesis in valleys that have existed for a long time and the soil properties they produce.

This study has several limitations. It is still limited to the analysis of several physical and chemical soil properties. Several important soil properties, such as cation exchange capacity, base saturation, organic carbon, bulk density, and clay mineralogy, are not covered in this study.

Also, the absolute ages of the various paleochannels are not yet available, so the relationship between landform development and pedogenesis cannot be determined accurately. In the future, further studies should be conducted to address other physical and chemical soil properties not discussed in this study.

D. CONCLUSION

Soil development is an integral part of landform development. Along with the dynamics of ancient landforms, soil also undergoes development. Here, we find soil characteristics indicating advanced development in the paleochannel at Grabag-Pringsurat, a Pleistocene landform.

Soil development is characterized by various physical and chemical properties of the soil, including a dark color with low value and chroma, large-sized clumpy structure, even massive, strong consistency with high cohesion and plasticity, and sandy texture.

Local climate conditions, parent material, topography, organisms, and even human activities also determine the physical and chemical properties of the soil. Surface soil has a high moisture content. Additionally, soil reaction tends to be acidic due to the various factors influencing soil formation.

For evaluation, there are still limitations in this study. This study is preliminary in the form of an initial survey, so the creation of genetic and diagnostic soil horizons does not accompany it. Future studies are highly recommended to describe soil properties in each horizon, accompanied by identifying soil types based on the nature and properties of the soil found. Thus, the soil survey will be more complete and provide comprehensive information.

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